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EFFECT OF DUAL FUEL MIXING PERFORMANCE IN RCCI ENGINE CYLINDER

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ABSTRACT

The combustion of the fuel in-cylinder of the engine can be affected by the fuel/air mixture and fuel/air equivalence ratio. The fuel/air mixture can generate the swirls when the fuel/air will be mixed in-cylinder. The formation of turbulence can effectively promote the combustion of the fuel, thereby causing the output of the engine. However, various fuels into the cylinder can cause different swirls. The RCCI technology consists of loading two different cetane fuels in the cylinder. To complete the reactive stratification, the less reactive fuel is premixed with air prior to charging into the combustion chamber. Subsequent injection of a more reactive fuel uses a direct injector. By properly controlling the fuel ratio and injection timing, it is possible to adjust the combustion by means of the reaction gradient, which can separate the phases and reduce the rate of pressure rise and heat release. At the same time, factors such as the compression ratio (CR) and the geometry of the piston bowl may affect the characteristics of the RCCI. The evaporation, mixing and combustion processes depend on the type of fuel. This paper describes comparing the degree of mixing of different fuels in an RCCI engine prior to the combustion process to find a suitable low reactivity fuel by comparison. The engine usually uses the fuels such as neat diesel, butanol, methanol, ethanol and n-heptane as the first stage fuel. Through these fuels into cylinder generate and compare swirls, a suitable fuel for CI engine is found because the important role of fuel combustion is fuel/air mixture swirls. Some papers observe that the n-heptane is an additional fuel that is suitable for engine. This paper will compare the effect of the n-heptane and gasoline into engine.

***KEYWORDS:** Swirl, In-cylinder, Fuels, Combustion & Fuel/Air*

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Original Article

1. INTRODUCTION

Diesel and gasoline engines are the most commonly used internal combustion engines in the modern life transportation sector. Diesel or Compression Ignition (CI) engines have superior combustion characteristics compared to gasoline or spark-ignition (SI) engines because they enable the fuel to be compressed with a higher compression ratio produced in the cylinder after it is injected into the cylinder. It does not cause engine knock, has less throttling loss, high combustion efficiency and good gas characteristics due to lean operation.

Most of the research on HCCI and PCCI on the world's fuels is tested and studied using high quality gasoline or diesel. However, the operation of PCCI has certain advantages and disadvantages due to the existing fuel and the composition of the fuel itself.

In order to maintain the high thermal efficiency output of the CI engine while reducing in-cylinder NOx generation and soot emissions within the exhaust gas, many new strategies for compression ignition and fuel combustion have been proposed. One of the most effective ways to achieve low in-cylinder NOx generation and soot emissions in CI engines, however, is HCCI combustion. Although the combustion of fuel in HCCI engines is thermodynamically influential, the idea presented by HCCI is a controllability challenge over conventional engines,

because it burns due to near constant volume, which can result in a very fast heat release rate and a very fast rate of pressure rise in the cylinder. In order to maintain the periodic control of the combustion process, it is necessary to make a relative adjustment between the fuel injection process and the magnitude of the combustion process [11]. The results of the HCCI engine have thus spurred engine researchers to accelerate and study the trend of PCCI combustion, a trend that is the perfect combination between HCCI and conventional DICI combustion. In order to reflect the relative stability between the initial fuel injection process and the initial combustion, in the state of PCCI, the injection of fuel should be injected as early as possible during the compression stroke to promote efficient mixing with the incoming air after the pre-ignition fuel injection, thus avoiding the generation of high NOx and avoiding the formation of soot emissions in the exhaust gas.

Many researchers in this type of engine research have shown that HCCI and the premixed charge compression ignition (PCCI) concept are among the most promising technologies for simultaneously reducing NOx formation in the cylinder and soot emissions in the exhaust [12]. Saxena *et al*. [13] recently reviewed the basic phenomena controlling the HCCI operations, which particularly emphasizes high load conditions. Emission characteristics were discussed and recommendations were made on how to achieve low emissions of all regulated emissions at a low price. Therefore, in such engines, the physical and chemical properties of different fuels are discussed. The research focuses on single-stage ignition and two-stage ignition. The molecular structure affects the vaporization of the fuel during combustion and is called helium-sensitive of fuel characteristics. Then, another importance of in-cylinder charging conditions is discussed. In a typical engine, different types of EGR and their effects are produced as well as the importance of thermal stratification and gas mixture stratification. The operational limitations of controlling high-load operation are also discussed in detail, and the most recent research is discussed.

Musculus *et al*. [14] describes the latest research on engines and combustion chambers using optical detection and boldly proposes a conceptual model of low temperature combustion (LTC). The model is based on simulations using various optical diagnostic observations and homogeneous reactors using detailed chemical kinetics. The model uses and describes in detail the conditions of low-load, single-shot, partially pre-mixed compression ignition with high EGR rate (with oxygen concentration in the range of 10–15%), and considers spray formation, vaporization, mixing and ignition, and a series of studies on pollutants, which destroyed its mechanism concept consistent with the experimental observation of LTC diesel engine.

Park *et al*. [15] studied the fuel characteristics of gasoline-diesel directly mixed fuel in a four-cylinder diesel common rail system, the droplet atomization of gasoline and diesel, the combustion performance and the exhaust emission characteristics of the final stage. In this study, it was found that gasoline distillation can reduce fuel density, kinematic viscosity and fuel surface tension. The results show that the addition of gasoline can extend the ignition delay because the gasoline contains less cetane, which effectively provides a more uniform fuel mixture. The combustion characteristics of such fuels can simultaneously reduce the generation of NOx in the cylinder and the emission of soot in the exhaust gas.

Kokjohn *et al* [16]. RCCI is a new technology for dual-fuel engine combustion. After the fuel in the cylinder is mixed with at least two different reactive fuels, multiple dual fuel injections are performed to control the in-cylinder fuel mixed combustion reaction to optimize the combustion phase, duration and combustion amplitude of the fuel. The process involved in RCCI involves introducing a low reactivity fuel into the cylinder to form a low reactivity fuel, a good mixed feed of air and recycle gas.

The low reactivity fuel is then injected into the combustion chamber through the air passage using single or multiple injections prior to igniting the premixed fuel, then the highly reactive fuel is injected directly into the combustion chamber through the nozzle, thereby achieving high-performance combustion of the engine, improving engine performance, reducing NOx generation and emissions of exhaust fumes.

Fuel is injected through a direct injection system to introduce stratification of the reaction zone within the cylinder. The dual fuel RCCI concept improves other modes of LTC engines, such as HCCI or PCCI by providing an accurate method of controlling heat release rate and combustion phasing. During the RCCI study, it was found that two fuels with different reactivity (including low reactivity fuel and highly reactive fuel) were mixed in the combustion chamber.

A schematic diagram of RCCI combustion is shown in figure 1. Low reactivity fuel (LRF), such as gasoline, is injected through a port fuel injector (PFI) in the intake manifold and then premixed with air. During the compression stroke, highly reactive fuel (HRF) diesel is injected into the cylinder through a diesel injector (DI). Injection of HRF is accomplished by a single, two or three injection strategy. The combustion phasing and combustion duration are controlled by spatial stratification between the fuel ratio and the fuel, respectively.

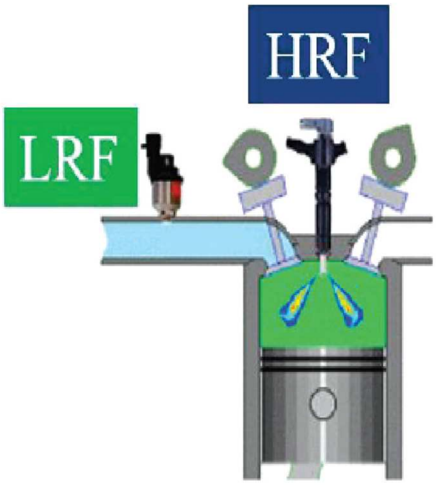


Figure 1: Schematic of RCCI Engine [16].

Although it is a commonly used engine in human life, diesel engines emit high levels of NOx and soot, which can cause environmental pollution. The important reason is that the fuel ratio affects the in-cylinder reactivity. In RCCI, engines can use low reactivity fuels such as gasoline, natural gas and methanol. Typically, diesel is used as a highly reactive fuel, and the low reactivity fuel has a higher evaporation rate due to its high volatility, and PFI can be used to obtain a premixed charge. Another reason is that the resistance to spontaneous combustion is enhanced due to the low cetane number to prolong its pre-combustion mixing time. For the reactivity expressed as CN, it can be calculated according to equation (1) as follows:

$$CN_{\mathrm{dual-fuel}} = \frac{CN_{\mathrm{low}}X_{\mathrm{low}}+CN_{\mathrm{high}}X_{\mathrm{high}}}{X_{\mathrm{low}}+X_{\mathrm{high}}} \tag{1}$$

Then, CN is the cetane number and χ is the mole fraction and the subscripts "high" and "low" denote high and low reactivity fuels, respectively. The fuel ratio is an important part of the blended fuel and can affect reactivity and

ignition delay. The LRF ratio affects and increases the ignition delay time before combustion. Many researchers have done a lot of research on this research, such as Li *et al*. [17]. The effect of fuel ratio on gasoline/biodiesel-fueled RCCI engines was investigated. They report that because of the more uniform combustion, the increase in gasoline can reduce NOx and soot emissions.

Although the fuel in the cylinder plays an important role in the combustion, the mixing ratio plays a certain role before the combustion, and only when the mixing ratio is high, the fuel used can be sufficiently mixed with the air. In the compression stroke, after the diesel injection, it can also be sufficiently mixed with the low reactivity fuel to make the combustion sufficient. Therefore, the primary factor affecting the mixing ratio is the physical properties such as viscosity and density of the fuel itself because these factors can change the turbulence ratio at the time of injection.

So, in this engine, the use of low reactivity fuels such as gasoline have difficulty achieving ignition mixture with air inject into engine at low–load conditions and high reactivity fuels, like diesel have difficulty controlling combustion phasing at high load condition, many researchers have investigated PCI operation using fuel blends.

In the RCCI engine, during the port fuel injection, the gasoline is used as a normal fuel into engine, sometimes the machine is required with a variable swirl actuator set up in the intake port because the fuel swirls plays an important role before combustion. However, some researchers made some research about the biofuel, as an additional fuel into cylinder, observed that the n-heptane suited the CI engine for reducing the exhaust emissions. So, this paper wants to compare the fuel efficiency with that of n-heptane because this fuel's flash point is very low and the auto-ignite point is high, so can be used as a low reactivity fuel into the cylinder.

This paper will deal with non-modified engine, compare the swirl characteristics of n-heptane and gasoline when injected into the cylinder.

In the article, the addition of low-reactivity fuel can effectively reduce the emission of exhaust gas, like gasoline is injected into the diesel engine as a low-reactivity fuel. The research of this fuel has been verified by many researchers and has been highlighted. Results: In the structure of the RCCI engine, the shape of the piston, the degree of mixing of the internal fuel, etc., can all affect the characteristics of the combustion. The most important thing is the physicochemical properties of the fuel itself. Due to their different characteristics, the eddy current shape and eddy current intensity internally caused after injection into the cylinder are also different. By comparing the degree of mixing, it can also affect the tail gas products produced during combustion. Everyone knows that gasoline is also derived from a fuel conversion. Now, the lack of resources and the demand for renewable resources are a temporary trend.

Only when the mixing before combustion is optimal, can we compare the next step and burn, which is a long process. So, first compare the degree of mixing of the fuel before burning.

2. ANALYSIS PROCESS

In this paper, the model will be set as the mesh displayed in figures 2 and 3 and set the valve lift size as 6 mm and make the plane 30; 45 and 60, respectively, compare three planes' swirl conditions, make the intake port size as 80 mm, cylinder size as 100 mm and the out-plenum size as 130 mm. In the above-described pattern, the narrow portion is defined as the cylinder block and the lower portion is defined as the out-plenum body.

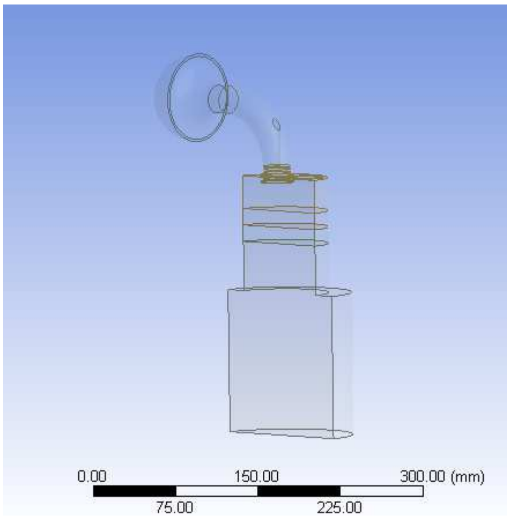


Figure 2: The Cylinder Geometry.

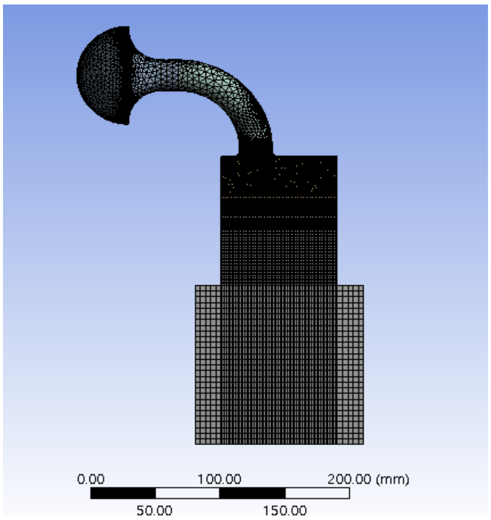


Figure 3: Geometry Mesh.

The degree of fuel mixing at the cylinder positions of 30, 45 and 60 when the injected n-heptane and the gasoline fuel were compared by the basic pattern described above. The degree of mixing with the diesel fuel after the injection is compared before the compression stroke is performed; however, the amount of eddy current generation plays a very important role when mixing. The compression ignition point of diesel is relatively low. In the compression process, firstly, diesel (highly reactive fuel) is burned, which ignites the injected fuel (low reactivity fuel) and produces stratified combustion, thereby reducing NOx emissions.

3. RESULTS

The injection of n-heptane and gasoline inevitably produces eddy currents in the cylinder. Due to the physical and chemical properties of the fuel itself, the vortex generation rate is different when the fuel is injected. The image vortex can be used to observe the eddy current caused by the cylinder position at different positions. It is also different like in figures 4 and 5.

It can be seen from the figure that a strong eddy current is generated when the cylinder position is close to the top of the cylinder, so that the internal volume is small at the time of injection, but the injection pressure is large, resulting in a faster injection speed, the average rate shown in figure 7 can be used as a reference. This causes the eddy current to be more pronounced during the initial intake.

It is found that near the top of the cylinder, the eddy current produced by n-heptane is stronger than those generated by gasoline. The main reason is that the density of n-heptane is smaller than that of gasoline, which affects the velocity of the flow and causes preliminary eddy current.

From the latter image, it can also be observed that at the 45 and 60 positions, the vortex intensity generated by the gasoline is large, and the eddy current intensity generated by the n-heptane is reduced. This phenomenon can also be observed in figure 7, mainly because of the high viscosity of n-heptane and the need for a large evaporation pressure as the solubility of n-heptane is relatively poor, only soluble in alcohols. These physical factors inhibit the dispersion of fuel and reduce the eddy current intensity.

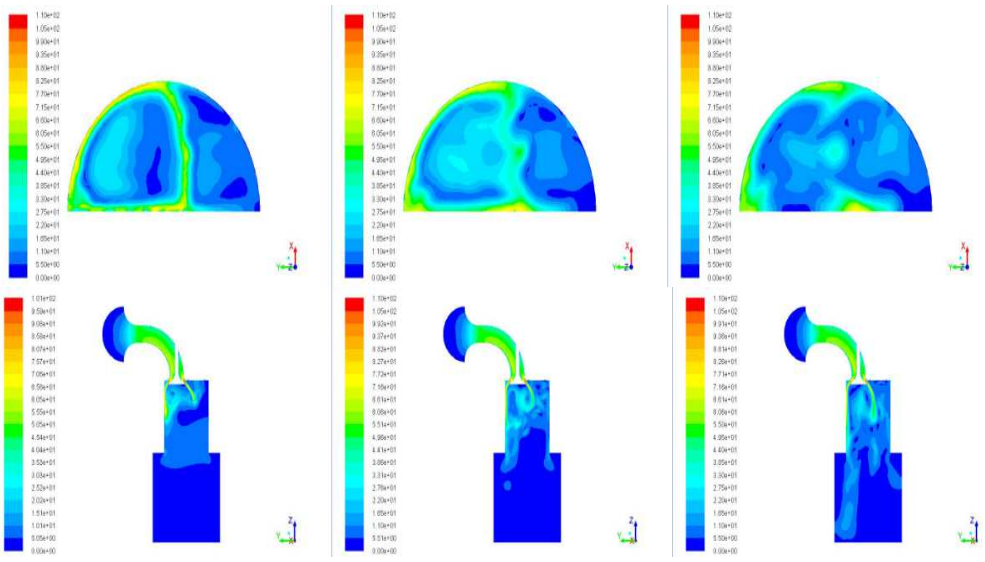


Figure 4: Eddy Current During n-Heptane Injection at 30; 45 and 60 Cylinder Position.

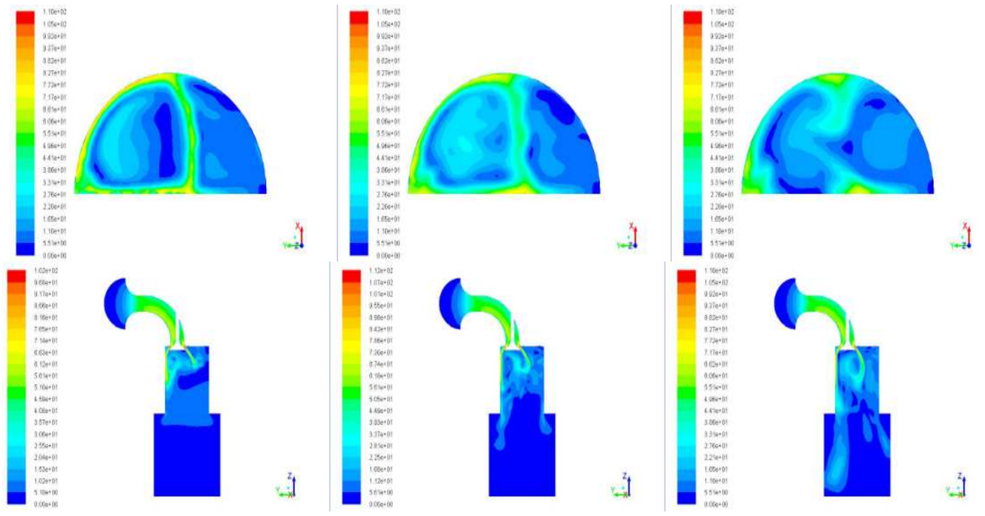
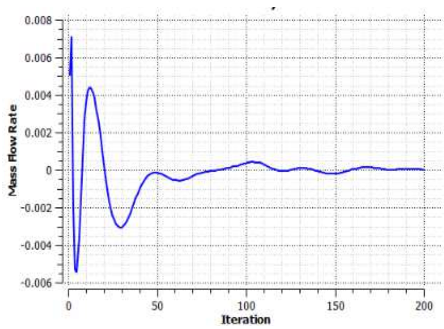
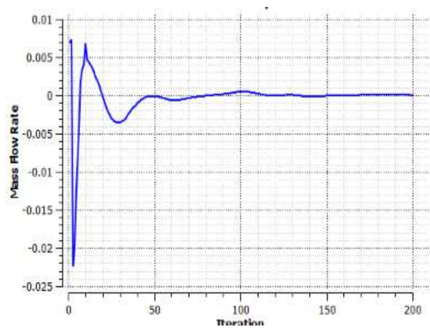


Figure 5: Eddy Current During Gasoline Injection at 30; 45; 60 Cylinder Position.

Figure 6 shows the flow rate of fuel injection through the curve. It is found that the injection amount of gasoline is less than that of n-heptane, mainly because of the physical properties of n-heptane. Higher fuel consumption can be achieved by achieving the same engine torque. The main reason is that, as described above, n-heptane has a high viscosity, a special solubility and a high vapor pressure to effectively evaporate to achieve effective mixing.

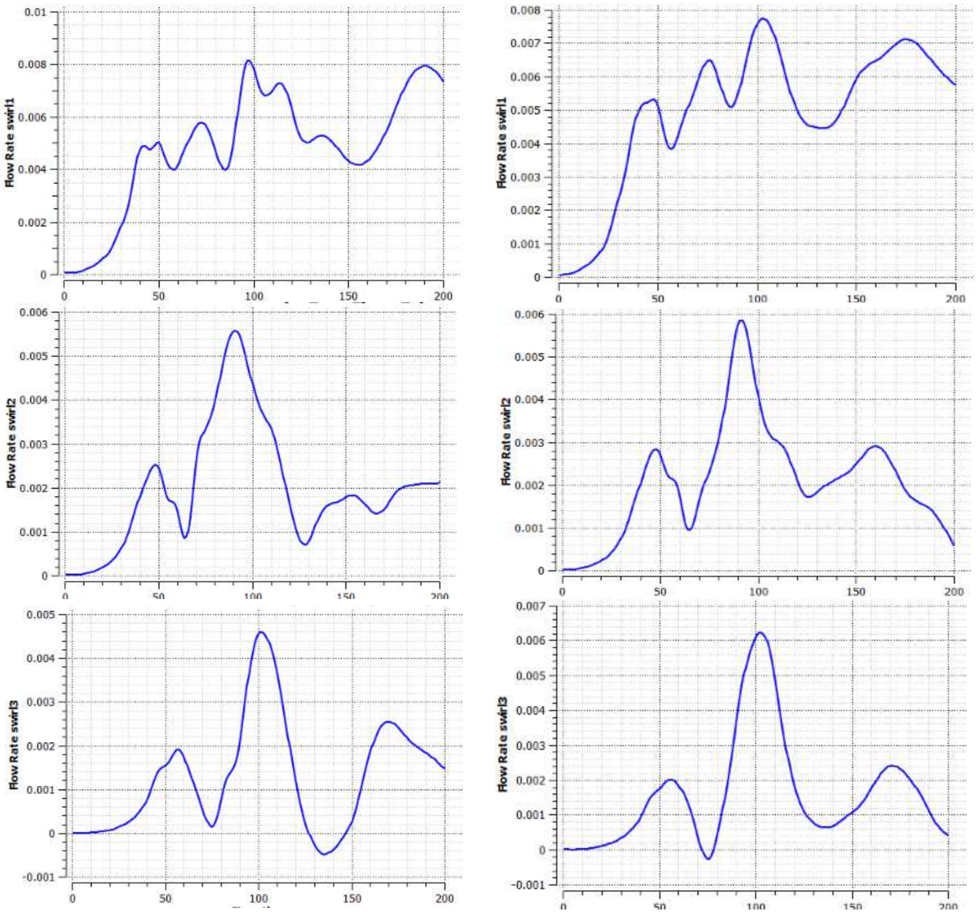


(a)



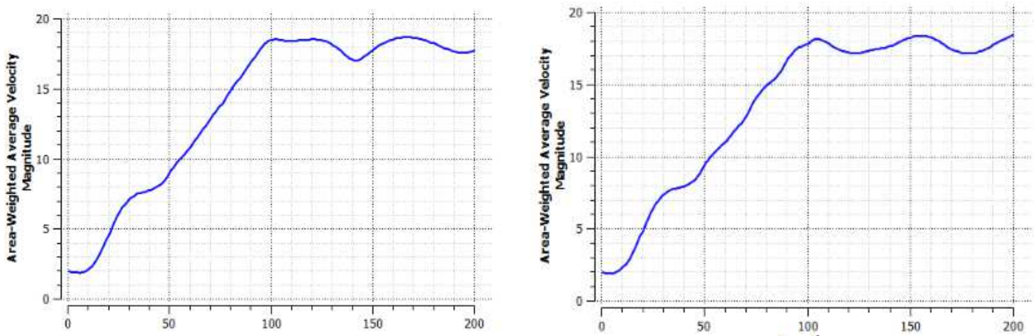
(b)

Figure 6: (a) n-Heptane and (b) Gasoline Injection at Different Positions.



N-heptane Gasoline

Figure 7: Eddy Current Distribution Curve at Three Different Positions.



N-heptane Gasoline

Figure 8: Area Weight Average Velocity of N-heptane and Gasoline at 60 Cylinder Position.

4. CONCLUSIONS

This paper examines the eddy current intensity generated in a cylinder when n-heptane is injected with gasoline and compares the magnitude of the injected amount. Different eddy currents are generated at different positions of the cylinder, mainly based on the different physical and chemical properties of the fuel, resulting in different results.

- In the paper, it can be found that the eddy current intensity at the initial injection (30 volume) is n-heptane. Due to the higher injection pressure and lesser volume, the injection speeds quickly.

- At the cylinder volumes of 45 and 60, the injection of gasoline produces a strong eddy current. After the diesel is compression-ignited in the RCCI engine, the gasoline is effectively burned to reduce the occurrence of knocking.

In future studies, the characteristics of combustion after mixing, the performance of the engine and the exhaust characteristics of the exhaust gas will be studied.

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